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Mainstreaming Energetic Resilience by Morphological Assessment in Ordinary Land Use Planning. The Case Study of Moncalieri, Turin (Italy)

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Received: 22 April 2020; Accepted: 25 May 2020; Published: 30 May 2020

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Abstract: Energetic resilience is seen as one of the most prominent fields of investigation in the upcoming years. The increasing efficiency of urban systems depends on the conversion of energetic production of buildings, and therefore, from the capacity of urban systems to be more rational in the use of renewable resources. Nevertheless, the integration of the energetic regulation into the ordinary urban planning documents is far from being reached in most of planning processes. In Italy, mainstreaming energetic resilience in ordinary land use planning appears particularly challenging, even in those Local Administrations that tried to implement the national legislation into Local Building Regulation. In this work, an empirical methodology to provide an overall assessment of the solar production capacity has been applied to selected indicators of urban morphology among the different land use parcel-zones, while implementing a geographic information system-based approach to the city of Moncalieri, Turin (Italy). Results demonstrate that, without exception, the current minimum energy levels required by law are generally much lower than the effective potential solar energy production that each land use parcel-zone could effectively produce. We concluded that local planning processes should update their land use plans to reach environmental sustainability targets, while at the same time the energetic resilience should be mainstreamed in urban planning by an in-depth analysis of the effective morphological constraints. These aspects may also represent a contribution to the international debates on energetic resilience and on the progressive inclusion of energy subjects in the land use planning process.

Keywords: energetic resilience; solar radiation; geographic information system; land use planning; urban regulation

1. Introduction

The attention on urban environment and energy emerges clearly from the end of the 1980s to the early 1990s, where the importance of integrating energy and spatial planning appears to be defined [1]. Starting from milestones as the 1992 Rio Conference, Local Agenda 21 and first studies on local planning and energy parameterization [2–6], the need for a systemic approach on energy topic and physical organization of the city became relevant. Today, in the light of the exposition to adverse events, whether due to the lack of energy sources or to climate change impacts and man-made stressors, it is increasingly evident that energy systems need to become resilient too. The concept of resilience is a central topic in the debate of natural and artificial stressors affecting cites, and therefore, should be more considered in the normative framework of Sustainable Development Goals (SDGs) [7]. Indeed, as stated by Sharifi and Yamagata [8], to be resilient, urban energy systems need to develop the capacity to "plan and prepare for", "absorb", "recover from", and "adapt to" any adverse event that may occur in the future [9]. The integration of these four abilities within the systems should improve its capacity to address "availability", "accessibility", affordability" and "acceptability", which represent the four sustainability-dimensions of energy [10,11]. Within this perspective, the resilient paradigm can be applied to the planning and building design criteria [12], as they have to deal with permanent conditions of change and often also with external pressures (from both socio-economic and natural dimensions). Because of this wide spectrum of uncertainties and dynamics associated with energy supply and demand, and since adaptation approach is the key for dealing with uncertainties, improving coping capacity and learning from unexpected and new circumstances, this work adopts an adaptive approach to energy resilience, also known as "socio-ecological" resilience [13,14]. The exploration of the relevance of this concept in the urban dimension for sustainable energy can provide several benefits [15,16]. However, for a long time, despite the introduction of energy issues in the field of urban spatial planning and urban form, the topic has mainly focused on the consumption of buildings, without addressing the needs to govern complex and articulated urban districts by municipal strategies and normative solutions by land use plans which might influence renewable-energy production and energy-savings. Therefore, examining the relationship between urban planning, urban morphology, and solar energy production represents a relevant topic that highlights the complexity and multi-dimensional nature of energy resilience [17]. Furthermore, addressing these issues in the planning process of modern towns may favor the functioning of cities, as socio-ecological systems, in time.

In this sense, some steps have been done internationally, and consider renewable energy issues at different scales. This has been developed as a collective and leading response to the international political goal of sustainability, in particular through two important documents: the European Directive 2010/31/EU and the European Directive 2012/27/EU of the European Parliament and of the Council [18,19]. t They introduced the EU 2020 targets that aim to reduce of 20% the Green-House Gas (GHG) emissions, to improve the energy efficiency of 20% and to use 20% of renewable sources for energy consumptions. In December 2018, the revised European Directive 2018/2001/EC on renewable energy and the Regulation 2018/1999/EU on the governance of the energy union and climate action entered into force, as part of the "Clean Energy for all Europeans Package" promoting a 40% of reduction in greenhouse emissions, a goal of 32% final consumption from renewable energy sources, and an energy efficiency target of 32.5% [20–23]. In particular, this package sets ambitious targets for all Member States in terms of energy from renewable sources by 2030 (32% share), in order to limit GHG emissions in compliance with Paris Agreement. The Regulation 2018/1999/EU provides for a structured and iterative process between the Commission and the Member States for the development and subsequent implementation of national plans. Indeed, in the new regulation, EU countries are required to develop 10-year National Energy and Climate Plans (NECPs) for 2021–2030, highlighting their strategies to meet the new 2030 targets for renewable energy.

In line with the European Directive, in December 2019, the text of the Italian Integrated National Plan for Energy and Climate (INECP) [24] was published, setting the national targets for the years 2021–2030. The INPEC establishes a percentage of energy from RES in the final gross energy consumption of 30%, a reduction in primary energy consumption compared to the PRIMES 2007 scenario of 43% and an overall reduction of GHG compared to 1990 levels of 38%. In Italy, the "Clean Energy for all Europeans Package" was implemented by the Decree D.Lgs 28/2011 and led to the definition of guidelines for energy performance certification of buildings (D.M. 26/06/2015), according to both classes of energy-performance, and economically sustainable indications for energy retrofit interventions [25,26]. Specifically, Article 11 completely redefines the criteria of renewable energy for buildings by introducing the obligation to integrate renewable sources in either new or existing buildings that are renovated by "major interventions". The article clearly states that in both cases, the transformation has to meet the need of using renewable sources to cover the consumption of space heating, space cooling, hot water and electricity, and according to the obligation of integration of the systems. Clearly, the interest in assessing the built-environment arises from all these recent European and national directives that promote renewable energy and environmental sustainability with clear goals to be achieved by each Community member [27]. At a local level, the Piedmont Region is promoting policies to facilitate the transition to a sustainable energy future also at a municipal level. Thus, the Regional Council introduced the European standards related to the Italian Decree n. 28/2011 to install and maintain energy systems powered by RES. In particular, the Regional Council of Piedmont introduced several innovations regarding the energy performance issue and in 2018 approved the regional law n.12 titled "Promoting the establishment of Local Energy Communities". Through this statute, the region promotes the establishment of Local Energy Communities (LECs), in order to facilitate the implementation of European, national and regional regulations of environmental sustainability [28]. In the so-called LECs, public and private entities are encouraged to cooperate for limiting the use of fossil fuels and facilitate the production and exchange of energy mainly generated from renewable sources [29]. Among a wide range of existing renewable energy production scenarios promoted by LECs, producing electricity from solar panels is the most popular and efficient at the urban level, since its modularity, easy installation, and relative economic affordability for private investors makes it applicable to different scales. In addition, the International Energy Agency confirms that solar energy could be the world's largest source of energy by 2050 [30], despite the strong dependence of this solution from individual choices. Therefore, collective approaches are undoubtedly helpful for promoting, facilitating and applying this solution to the largest audience. However, to optimize these collective approaches, it is necessary to prepare urban adaptation plans that regulate and facilitates the transition of the built-up system towards the more efficient and rational use of solar energy production. While doing so, cities have to prepare an analytical assessment of the relative solar-energy potential of different urban areas with the main influential urban-form features, and successively integrate that knowledge into the most effective urban planning strategies and policies; otherwise, the risk is to leave the energetic transition happening without real coordination among the land use owners, their rights to transform the urban scenario of cities while installing solar panels; thus, their potential capacity to optimize and reconvert their buildings. The question that here arises is: How can energetic resilience transition be mainstreamed by land use plans if there is no systematic assessment of the solar capacity production in cities? Moreover, how is the solar energy production affected by the morphological conditions of the city?

In this sense, land use plans may play a key role in integrating and introducing the renewable energy component in the ordinary planning activity. In response to these compelling needs and in accordance with several national and regional legislation (L. 373/1976; L. 10/1991; L.R. 31/2000; D.Lgs 192/2005; D.Lgs 152/06; L. R. 13/2007; D.P.R. 59/2009; D.Lgs 28/2011; L. 90/2013; L.R. 3/2015; D.M. 26/06/2015), on 6th April 2016, Moncalieri municipality (in Piedmont Region, Northwest of Italy) through the City Council Resolution n.34, approved the Energy Attachment to the Municipal Building Regulation [26,31–40]. In addition to the general objectives related to the efficient use of energy and water sources, reduction in CO_2 and polluters emissions, and higher quality of the indoor environment; the document promotes an improved efficiency of buildings through solar energy for planning purposes. Furthermore, it sets a series of laws referred to a minimum level of energy-quality to be mandatorily achieved in every intervention. However, despite the wide attention dedicated to the qualities of the building stock, the document still lacks a planning perspective on morphological properties of the built environment. In particular, there is a gap between the effects of Moncalieri urban form on solar energy potential, in connection with the land use parcel-zone division and the new energy purposes of the municipality. In other words, neither the physical status quo of the city nor the existing plans, fully comply with the mandatory energy incentives introduced by the new regulatory attachment and with the real morphological properties of Moncalieri built environment.

In order to overcome this discrepancy, this paper performs a comparative analysis of the existing regulations, the main morphological features and energy potentials of Moncalieri and the possible local planning perspectives. The main reference for this analysis is the local land use plan (LUP), which seeks to order and regulate municipal land uses in an efficient way. In the Italian legal systems, the land use plan is a mandatory planning tool that regulates building development by different morphological units (e.g., land use zones—LUZ) within the municipal area. It provides a vision for the future possible developments in neighborhoods, cities, or any land use normative areas. Furthermore, thanks to its detailed and thematic plans, the document can zoom on specific services and public interests, as for the case of energy topic. Here, in particular, there is an opportunity to introduce more directly morphological criteria that are related to settlement types, compactness ratio, density patterns and the configuration of the urban built environment, so that their role becomes evident to mainstream energy resilience.

That clarified, the paper starts with quantifying the solar energy production potential of the buildings and continues with translating the single measures for each building to a larger geographical scale according to the land use development zones in the municipal plan. In addition, it illustrates some morphological features of compactness and density to highlight the effects of different annual solar irradiation thresholds on the energy potentials of roofs [28]. It also underlines the relevance of integrating solar energy issues in land use planning, while using GIS models to support solar urban planning practices.

The reason to work on a larger urban size (from buildings to land use zones) is mainly related to the coherence with the LUP, which divides the municipal territory in LUZ, and thus, allows for broader reflections on energy potentials at the municipal level, rather than on exclusive building scale. Subsequently, by unpacking the correlation between some common urban features and solar energy potential, it facilitates the process of revision of the renewable energy system at the municipal spatial planning level. In terms of sustainable principles, this perspective can clearly link the over mentioned levels of "availability", "accessibility", affordability" and "acceptability" of solar energy with a direct application on the case study. This is also possible as the work offers a comparison between the national minimum requirements of solar energy (according to Allegato 3 of D. Lgs n.28/2011) and the relative energy production based on local sources of energy [37]. The chapter ends with some suggestions for the decision-making level regarding the integration of the existing planning strategies and the real energy-production potential at the level of land use development zones. The results may represent useful support in the international discussion about the decision-making process for planning and integrating solar potential in over layered, dense and compact built environment. In addition, they also indicate the relevance of energy resilience for the urban system, not only for increasing public transparency and citizens awareness on environmental sustainability targets, but also in response to future energy requirements and to long-term perspectives of the city at economic, social and environmental levels.

2. Materials and Methods

This section starts with the introduction of the case-study and the relevant concepts such as LUZs, with the help of maps and tables to clarify the explained concepts. Subsequently, we present the indicators examined and calculated; and finally, we provide an explanation of the procedural ESRI ArcGIS (ver. 10.8) elaborations, which led to the solar energy production potential (SPP) index, considerable as the most relevant indicator of the study.

2.1. Case Study

The City of Moncalieri (IT) -represented geographically in Figure 1- directly south from the City of Turin, is part of the Metropolitan area of Turin (north-west Italy). It is located in the western part of the Po Valley at 260 m a.s.l. of altitude, surrounded by the Alps crown, and with a continental, temperate climate (Italian climate zone E). The orography is quite heterogeneous with flat fluvial areas in the southern and western sectors, while in the north-east the hills shape the landscape with its natural areas mixed with a typical sprawled settlement system (detached and semi-detached single-family houses). The municipality has a population of 57.527 inhabitants (last updated on 31 December 2019, ISTAT) [41], and consists of about 6.200 buildings [42,43].

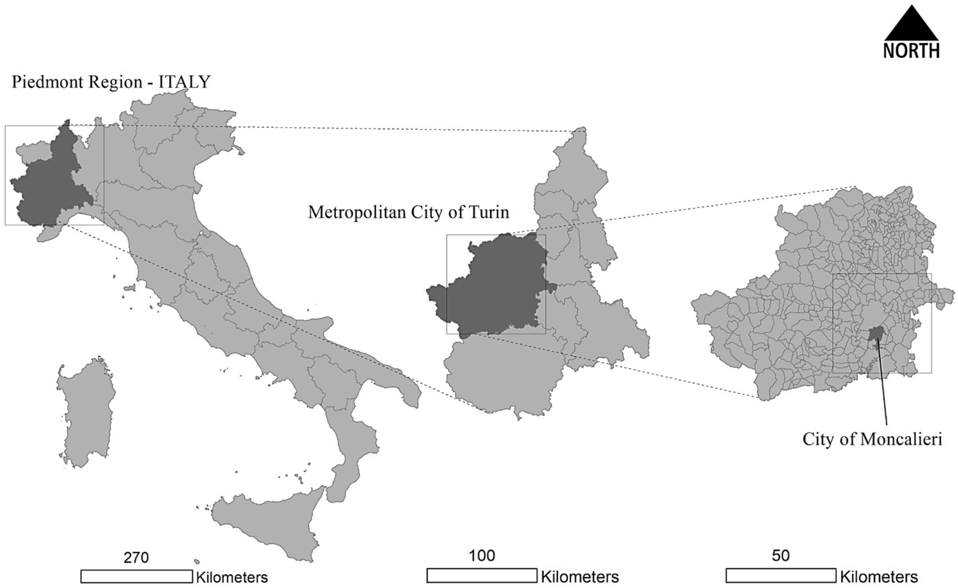


Figure 1. Geographical representation of the city of Moncalieri.

The land use is categorized as follows—34% urban areas, 39% agricultural land, 14% natural and seminatural, 4% other natural areas, 6% infrastructures, and 3% water bodies. The anthropic system, also considering infrastructures, is densely developed, covering the relative majority of land uses and threatening the environmental system (e.g., urban footprint by impermeable materials). Over the last few years, Moncalieri has experienced an expansion mainly in the hilly parts of the territory, due to a more flourishing real-estate market based on high-quality single houses in a surrounding green system and scenic view of the foothill areas.

The methodology hereafter presented is based on the calculation of two main groups of indicators, referred to (i) the on the energetic character of each LUZ and (ii) the morphological characters of each LUZ. Then, considering how each LUZ perform in terms of energetic production, we looked at how the potential energetic production differs from the minimum by the National Legislation.

To what concerns the morphological profile of LUZ, when dealing with solar energy in the built environment, compactness is a central parameter that influences the energy potential, and that determines different energy-performances according to the urban morphology. It is usually considered in the urban analysis, assessed in several ways, and deepened through several indicators related to the built-up environment. Furthermore, compact cities are particularly promoted in Sustainable Development Agendas and Policies of many countries, especially for reducing GHG emissions and urban-sprawl phenomena. The goal of the methodology was indeed to define a minimum solar energetic production threshold for each morphological unit linking energy production with urban planning regulation, starting from the minimum requirements of the Italian D. Lgs.28/2011 [25].

All the indicators hereafter presented are calculated using the tools of ESRI ArcGIS in a Geographic Information System environment using the digital shapefile of municipal LUZ to clip each information and extract tabular statistics at the normative-zone level. Table 1 represents all LUZ in the city of Moncalieri and gives a brief explanation about each zone and subzone.

Table 1. Land use zones in the city of Moncalieri.

Land Use Zones (LUZ)	Explanation
ZONE A—Urban settlements with historical-artistic or environmental character	
Ar1—Historical center	Built-up areas constituting the historical centers where the interventions are specified in the 1: 1000 scale works of the LUP
Ar2—Small settlements with environmental value	Smaller settlements, incorporated in the urban agglomeration or constituting the original settlement fabric of the villages of the agricultural plain
Av—Hilly areas of environmental interest	Hilly areas with relevant environmental interest. Single manufactured buildings not included in buildings of category Ar3 are also part of Av, including areas of relevance.
ZONA B—Parts of the territory largely or totally built-up	
Br—Residential areas largely built-up	Built-up areas of consolidated settlement.
Bp—Production areas	Areas with prominent existing production destination which are confirmed in their location.
Bpr1—Transformation areas with mainly tertiary use	Areas with prominent-existing production destination with a propensity for transformation from strictly productive activity to tertiary, exhibition, managerial, hospitality and residential activities (art 13, point f, LUR)
Bpr2—Transformation areas with mainly residential use	Areas with prominent-existing production destination with a propensity for transformation from productive activity to mainly residential use (art 13, point f, LUR)
ZONE C—Parts of the territory of completion or new	
Cr—Areas for residential use	Areas mainly for residential use or under construction
Crs—Areas for residence and public services	Transformation areas from public services to areas set partly to residential and partly to public services.
Crc—Areas for integrated shopping center	Transformation areas from public services to areas destined in part to an integrated shopping district and in part to services for trade and residence (V. Sestriere), art. 13, point e, LUR.
Cp—Production, commercial and tertiary areas	Production, tertiary and commercial areas
ZONE D—Parts of the territory destined to industry, artisans and tertiary sector	
D Zone	Areas with prominent production destination (art.13, point g, LUR)
LUP variant	Vadò Industrial Area
ZONE E—Parts of the territory set for agricultural use	
Ee—Free areas of the rural area in plain	Hilly and plain agricultural areas
Ep—Built-up areas used for extra-agricultural uses	Ensemble, buildings, facilities or artefacts which at the time of the adoption of the preliminary project were destined for non-agricultural production activities with the function of storage or warehouse not connected to the management of the farmlands
Es—Nurseries	Special agricultural areas for nursery activities
Es1—Permanent greenhouses	Special agricultural areas for flower activities

Table 1. *Cont.*

Land Use Zones (LUZ)	Explanation
ZONE F—Facilities and facilities of general interest (art. 22 ex LUR 56/77)	
FV—Public park areas (Urban and District)	Areas of urban and local public parks
FH—Social health and hospital facilities	Areas set for existing and projected public hospital facilities
FHP—Social health and hospital private facilities	Areas just as FH but private
FI—Higher education facilities	Areas destined to facilities for the compulsory high education public-sector
FIP—Private higher education facilities	Areas just as FIP but private
Ft—Areas for technological systems	Areas destined for technological systems of general interest (ENEL, GAS, Waste Collection, Purifiers, etc.)
Frp—PTO area set for mixed-use and leisure	Areas for sports and leisure activities included in the Environmental Protection and Valorization Area of PO river—PTO (DCR 08/03/95 n. 981–4186)
Fg—Areas for general facilities of public interest	Areas destined to other general public interest facilitates specifically indicated in the cartography section (fire department, police station, magistrate's court, library, financial offices, etc.)
Fe—Religious areas	Areas with existing buildings mainly destined for religious use (convents, boarding schools, etc.)
Fr—Areas for recreational activities included in the Po river belt	Areas for social, cultural, sporting, recreational and private activities included in the Area Plan of the System of Protected Areas of the Po River (DCR 982–4328, 08/03/95—LR 68, 13/04/95)
ZONE S—Public spaces (art.21 ex LUR 56/77)	
S—Services	Public Facilities
Sr—Residential services	Public areas and facilities related to residential settlements
Sp—Productive, commercial, tertiary and accommodation services	Public or public use areas for facilities serving the production, tertiary, management and commercial settlements
Srp—Private residential services	Existing areas just as SR but private
ZONE T—Special transformation areas	
TCR—Areas for tertiary activities, residence and services	Areas of transformation from services to residence, tertiary, and commercial activities, and services (art.13, points e–g, LUR)
TR—Areas for management and tertiary activities	Transformation area from residence, mixed industrial and handicraft uses of mainly directional and receptive areas, with residence (beginning of C. Trieste) (Art.13, point e, LUR)
TE—Areas with a predominantly exhibition tertiary sector	Areas already with services that can be transformed mainly into tertiary, exhibition and/or residential areas
OTHERS—Other zones	
Railway site	Railway site
Cemetery area	Cemetery areas
Environmental Protection Area	Areas under restrictions for the protection of natural beauty or for the protection of areas of particular environmental interest
Street furniture	Street furniture (junctions, medians, traffic circles, streamside trees, etc.)

To simplify the large collection of land use zones and represent it in a map (Figure 2). we have selected the nine macro-categories, and the four specific land uses over-mentioned: Three A areas, four B areas, four C areas, two D areas, three T areas, four E areas, four S areas, ten F areas, and four so-called "other zones".

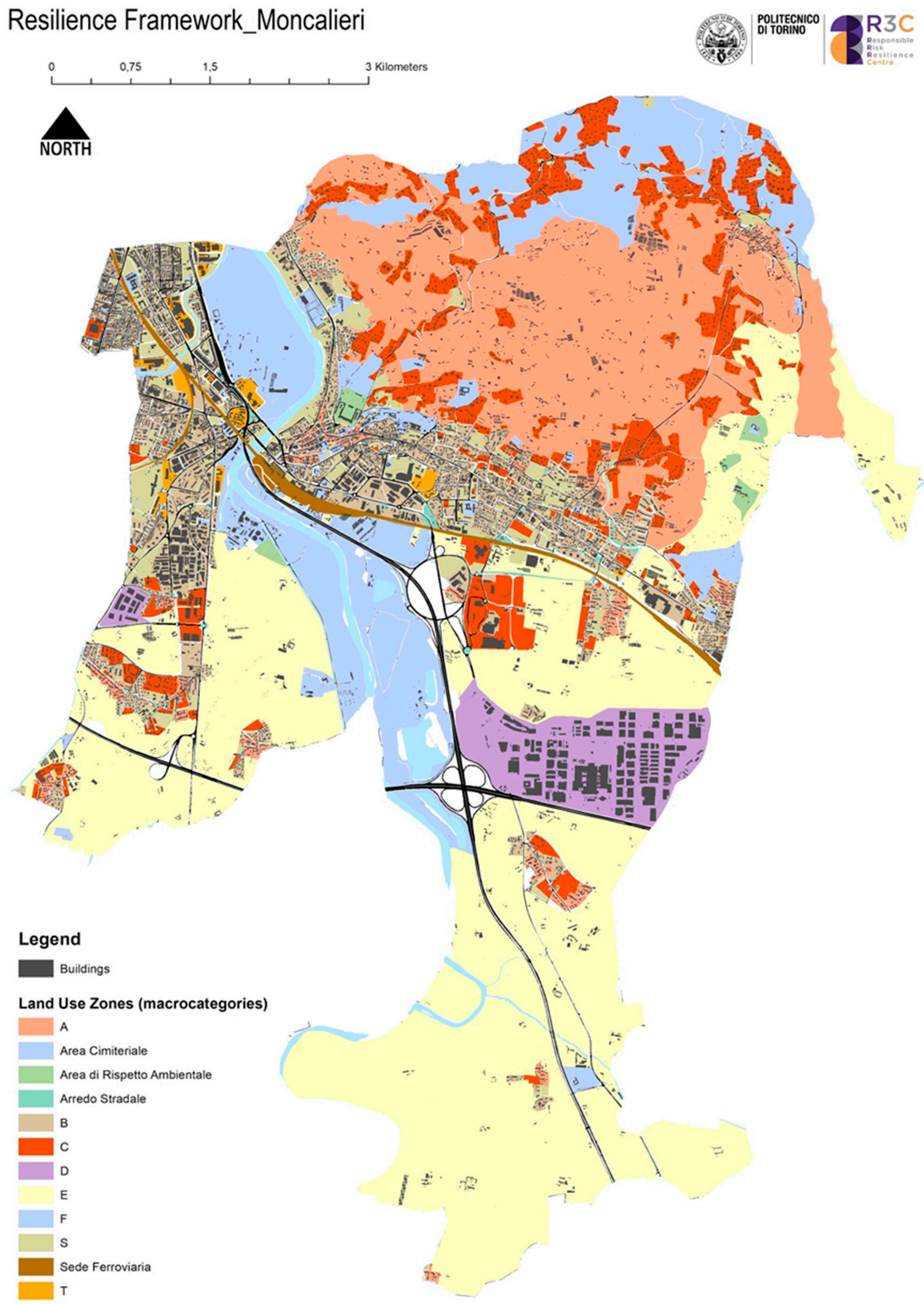


Figure 2. Graphical representation of the land use zones in the city of Moncalieri.

However, the measures for the indicators explained below will be presented for every normative zone in the city of Moncalieri in order to provide a deeper understanding of the energy potentials.

2.2. Description of Indicators

In this section, a set of indicators—to be calculated and analyzed for each LUZ—is presented and categorized in two main groups. While the first category refers to the energy performance of the buildings in each zone, the second one is related to the morphological profile of the area. This categorization enables us to make different scales of comparative analysis. The first scale relates to the comparison of different energy indicators; the second one refers to the comparison of morphological indicators with each other, and the last one is the confrontation of these two categories in order to clarify any probable correlation between energy and morphology in LUZ. To deepen the correlation between indicators of compactness and energy in different normative zones, some normalization passages have been developed, followed by regression analysis between indicators. Theoretical passages will be described afterwards and presented in the results section.

The energy indicators can be divided into two types: The indicators of solar energy production potential (E and $\overline{E}$), and the indicators referring to the regulatory minimum amount of photovoltaic energy power to be installed in each zone (P and $\overline{P}$). The first indicator is calculated by the help of GIS elaboration, in which the accumulated annual solar irradiation on the building roofs is converted to the solar energy production potential of the zones. The process of this calculation and conversion will be explained in the next subsection in more details. The second indicator is evaluated according to the Italian Decree D. Lgs 28/2011 [25]. This value is calculated using the formula of the Attachment n. 3 to the National Decree, to measure the minimum energy power of photovolitaic technology that should be installed in relation to the total building surface in a certain land zone area and the "K" coefficient equal to 50. For simplifying the calculations, the formula assumes that all buildings are installing solar panels for energetic production after the 1st January 2017. These two types of indicators are selected since the energy production potential, and the regulatory requirements are expected to follow a positive correlation. To be more specific, if the buildings of a particular LUZ are capable of producing relatively more amount of solar energy, the regulations should also comply with this potential and vice versa. Both indicators explained above are presented in total and average values in each zone. This enables us to compare both the values of the total amount of energy for the whole LUZ, and the average values for a single building, taken as a sample in each zone. This quantifies both the total amount of solar energy that each LUZ has to produce in the next future as a minimum requirement of the LUP, and the quantity of solar energy that each building have to produce averagely in each LUZ as a parameter to "set" the minimum standard for urban transformations.

The second category of indicators is related to the morphological measures in the LUZs. Although all three indicators in this category are compactness measures, each of them has specific features. While plot ratio is the outcome of the relation between total floor area and the size of land upon which it is built, site coverage represents the 2D compactness of the zones, while absolute compactness illustrates the 3D version of it since it includes the volume of the buildings as the principal variable. In order to make a comparison between these indicators possible, it is necessary to normalize all of them as they present different units of measure. Indeed, normalization is a process to organize data in a database and to make them more regular and comparable [44].

The process of normalization is done by dividing the value of each indicator to the sum of values of the same indicator and multiplying the measure by 100. In this case, the value for each LUZ is represented as a percentage of the total amount. In other words, all three indicators are normalized into a range between 0 and 100. As mentioned earlier, these three morphological indicators are also supposed to be compared with the energy indicators. In order to enable this comparison, the total solar energy production potential of the zone (E) is selected as the main indicator. This indicator is divided by the total roof surface of the zone in order to be representative of the production potential of one square meter of the building roof in each LUZ. Finally, the same normalization procedure is applied to these values to make the comparison more uniform and coherent.

Table 2 provides a theoretical overview of both energetic and morphological indicators adopted in this study. In addition, a precise description, the mathematical formula to obtain the indicators, units of measures and all the relevant variables—which are used for the calculation of each indicator—are presented.

Table 2. An overview of the indicators measured for the land use zones.

Category	Indicator	Abbreviation	Formula	Unit	Variables
Indicators of Energy	**Regulatory Minimum for Solar Power (Total Amount for the LUZ)** The indicator refers to the Minimum requirement by the Italian D. Lgs 28/2011 (KW). This value is calculated using the formula of the Attachment n. 3 to the National Decree, to measure the minimum energy power installed in relation to the total building surface in a certain land zone area and the "K" coefficient equal to 50. The formula assumes that all buildings are installing photovoltaic modules for electrical energy production after the 1st January 2017.	P	$P = \left(\frac{1}{k}\right) \times s$	kW	**S** = total building footprint of the zone (m^2) **K** = corrective coefficient (m^2/kW)
	Regulatory Minimum for Solar Power (Average Amount for a Representative Building in the LUZ) The indicator, in line with the previous one, refers to the Minimum requirement by the Italian D. Lgs 28/2011 (KW). The difference, in this case, is related to the scale: $\overline{P}$ is an average value referred to a representative building in the land use zone.	$\overline{P}$	$\overline{P} = \frac{P}{n}$	kW	**P** = Regulatory minimum for solar power (total amount for the zone) **n** = number of buildings in the normative zone
	Total Solar Energy Production Potential of the LUZ This indicator relates the annual solar irradiation in the normative zone (kWh/m^2/a) and the net surface of the panels installed in the zone (m^2), with respect to the index of the system performance and the conversion efficiency of the panel. The value represents the capacity of solar irradiation which can be turned into solar energy, without remaining simply at the minimum thresholds suggested by the national law. It has been calculated starting from the annual solar irradiation in the normative zone, and thus, represents the whole land use zone energy potential.	E	$E = PR\, H_S\, S\, \eta$	kWh/year	**PR** = index of the system performance **H_s** = accumulated annual solar irradiation in the normative zone (kWh/m^2a) **S** = net efficient surface of the panels installed in the zone (m^2) **η** = conversion efficiency of the panel (m^{-4})
	Average Solar Energy Production Potential of the LUZ The indicator, in line with the previous one, refers to the average annual solar irradiation in the normative zone (kWh/m^2/a) related to the average surface of the panels installed in the zone (m^2). Focusing on the average value, it refers to a representative building in the land use zone.	$\overline{E}$	$\overline{E} = PR\, H_S \overline{S} \eta$	kWh/year	**$\overline{S}$** = average efficient surface of the panels installed in the zone (m^2)
Indicators of Morphology	**Absolute Compactness** This indicator refers to the total building volume in a LUZ (m^3), divided by the LUZ total area (m^2). It gives the potential quantity of cube meters that are built in each LUZ, therefore representing the compactness of settlements.	Ac	$Ac = V/A$	m^2	**V** = sum of the buildings' volume in the normative zone (m^3) **A** = total land area of the zone (m^2)
	Plot Ratio The indicator refers to the total gross floor area (GLA) in a land use zone divided by the total area of a land use zone in which the buildings have been built. The average of GLA (m^2) captures the average of gross floor area per land use of a site. For instance, a one-story building that extends on an entire site has a high gross floor area which, in turn, is reduced when floors of the building increase. The indicator is a key variable to control and regulate land use zoning and development control of certain areas, since it regulates the built-up density among different LUZ.	Pl	$Pl = GLA/A$	ratio	**GLA** = gross floor area of the buildings in the zone (m^2)
	Site Coverage The indicator is based on the relation between the total building footprint on the LUZ and the total surface of the LUZ. Being based on the building-footprint and land-coverage, it can also be considered as the bi-dimensional representation of building footprints on a site. The horizontal distribution of built forms is crucial to understand the level of compactness of buildings and consequently, the physical conditions determining the solar energy producibility.	Sc	$Sc = S/A$	ratio	**S** = total building footprint of the zone (m^2)

2.3. Solar Radiation Analysis

To measure the solar energy production potential of the zone, we adopted the ESRI ArcGIS tool which is capable of detecting the annual, monthly or daily solar radiation distribution on municipal location in each pixel of the selected catchment area of about 47.52 square kilometer. The energy produced by buildings has been the output of the Solar Radiation analysis (therefore producing a Solar Radiation Index). The index E, total solar energy production potential, has been calculated for the entire catchment area (entire municipality) while enabling to analyze the effects of the solar radiation over the whole geographic zone of Moncalieri for each land use/land cover feature.

As the main input, it has been used the Digital Surface Model (DSM) (1 Band 32 Bit raster grid version, Cell-size 1-m, 99,258,750 pixels) to develop the Points Solar Radiation tool to calculate the amount of radiant energy of each pixel. In brief, our digital surface model represents the earth's surface and includes all objects on it. There, it is possible to calculate the radiant solar energy that hits the earth's surface, also called "global radiation" on a surface. This map refers to a 3D solar irradiation model of the built environment and the shadows brought by natural and artificial obstructions [45], elaborated from the monthly values of solar irradiation and the atmosphere transparency in Moncalieri. We employed the "standard" radiation parameters, setting 8 Zenith divisions, 8 Azimuth divisions the "uniform_sky" diffuse model type (meaning that the incoming diffuse radiation is the same from all-sky directions), a diffuse proportion of the sun components of 0.3 and a transmissivity of the atmosphere of 0.5. This model was corrected considering the characteristics of sun and atmosphere in Moncalieri with a seasonal interval; the annual average values were: The diffuse proportion of the sun components of 0.4 and a transmissivity of the atmosphere of 0.49. The seasonal data have been used to calculate the solar irradiation on the building-roofs and then the potential of energy producible by current solar technologies available on the market [27].

The system has stored each DSM-pixel as point features with x, y coordinates in the municipality. During the analysis, the tool internally calculates the sun position in the sky while finding the incidence of the radiated parts of the digital surface, and contemporarily, the shadowed parts. The quantity of solar energy for each pixel is delivered in point shapefiles for each month of an entire year.

Once the model provided the solar radiation, the different monthly shapefiles were joined in a single point file with the total yearly solar radiation. Then, since our focus was to calculate the energetic production for each building (thus assuming that solar panels are installed in the rooftops and not in the plots, gardens or other private properties around the buildings), the point shapefile has been intersected using the polygons of buildings, reaching a consistent reduction of fields.

The resulting shapefile has been statistically treated using MS Excel to transform the multiple point information contained for each part of the roof in an average Solar Radiation quantity. In doing so, the "pivot" function has been applied to calculate the average yearly radiation values for roof surfaces with similar values. The shift from Solar Radiation to energy production has been reached while considering the following characteristics of the used photovoltaic technology:

(i) the system performance ratio of 0.75; this parameter assumes that the in-situ performance of panels is lower than the performances in standard conditions in a laboratory; it should increase along with the years of utilization, and in this case, it has been assumed as a fixed parameter, and;
(ii) the energy production is a function of the number of panels, the peak power installed, and the energy conversion efficiency (e.g., it was considered a monocrystalline silicon technology panel with an annual average conversion efficiency of 12.5%) [46].

The final energetic production (kWh/year) has been evaluated taking into account that the average annual electric consumption of a family in the Moncalieri is about 2180 kWh/family/year [47].

For making the obtained values understandable in the context of normative regulations and make the comparative analysis possible, the single values of the energy production potential of each building have to be converted into a value of production potential of the normative zone. This passage was done through two simple mathematical operations. First, summing up all the average values for single buildings represented as E (kWh/year) and second, by dividing this indicator to the number of buildings in each zone to get the average zone value. These passages produced then an average value of solar radiation for each normative zone, useful to make comparisons and interpret the main findings. In the next session, the results obtained from these operations will be presented and comparatively analyzed.

3. Results

In this section, all measures for each of the indicators explained above are presented for the LUZs in the city of Moncalieri. For the first four indicators—Which refer to energy production—The values are comparatively analyzed. In addition, the three other indicators represent the level of compactness in each normative zone. Table 3 summarizes all the results regarding the above-mentioned analysis in each LUZ.

Table 3. Obtained measures for the energetic and morphological indicators in the city of Moncalieri.

Normative Area	E (kWh/Year)	P (kW)	$\bar{E}$ (kWh/Year)	$\bar{P}$ (kW)	Ac (m^2)	Sc Ratio	Pl Ratio
Ar1	7,251,843.42	1732.97	10,664.48	1.54	2.29	0.28	0.63
Ar2	7,938,326.26	2296.66	8656.84	1.52	1.33	0.28	0.37
Cemetery area	9803.27	212.65	9803.27	0.63	0.70	0.15	0.24
Environmental Protection Area	1,826,377.54	512.91	28,990.12	3.51	0.81	0.07	0.25
Street furniture	765,407.53	143.89	12,547.66	1.27	0.26	0.05	0.08
Av	12,938,375.19	6118.48	12,722.10	2.22	0.17	0.04	0.05
Bp	25,124,828.24	7233.49	75,779.95	6.14	2.92	0.42	0.52
Bpr1	3,570,421.28	1004.90	84,064.95	5.05	3.09	0.48	0.76
Bpr2	2,245,036.75	655.04	25,104.18	3.02	2.01	0.43	0.62
Br	60,903,302.93	19,093.38	15,363.80	2.12	2.67	0.31	0.78
Cp	6,112,824.33	1393.46	105,097.36	11.81	0.27	0.15	0.20
Cr	22,701,407.24	6965.30	12,329.69	2.03	0.58	0.12	0.18
Crc	650,321.96	211.16	81,290.25	7.82	0.67	0.43	0.71
Crs	628,703.64	194.84	13,017.42	1.89	0.14	0.09	0.16
D	1,869,508.36	670.60	54,985.54	21.63	1.32	0.31	0.39
Ee	14,457,837.48	4927.15	15,546.06	1.99	0.06	0.02	0.02
Ep	1,524,901.92	389.52	30,498.04	3.61	1.74	0.30	0.35
Es	181,398.31	46.42	90,699.15	6.63	0.83	0.39	0.76
Es1	106,300.39	24.13	35,433.46	4.83	1.57	0.63	0.63
Fe	1,076,069.35	273.51	40,800.25	3.38	1.17	0.12	0.36
Fg	1,034,831.13	255.31	29,566.60	4.91	2.05	0.36	0.74
Fh	438,061.65	80.47	41,035.03	1.52	3.95	0.30	1.22
Fhp	64,626.40	14.97	64,626.40	1.00	0.20	0.02	0.06
Fi	880,981.07	282.78	51,822.42	5.54	2.62	0.23	0.83
Fip	1,182,791.57	303.96	15,906.72	2.17	1.83	0.18	0.54
Fr	1,144,473.75	319.86	34,850.70	3.20	0.07	0.02	0.02
Frp	341,091.83	96.76	10,554.40	2.85	0.26	0.05	0.08
Ft	2,843,457.26	694.14	25,857.56	2.41	2.03	0.18	0.38
Fv	3,245,660.78	1035.81	36,627.89	1.51	0.04	0.01	0.01
S	49,353.94	14.42	6169.24	0.72	0.02	0.01	0.00
Railway site	2,371,320.36	238.94	30,016.71	1.11	0.16	0.03	0.05
Sp	896,358.06	80.63	57,924.64	2.78	0.10	0.04	0.05
Sr	15,521,895.56	3463.24	29,706.28	2.31	0.79	0.12	0.23
Srp	1,352,786.36	140.73	37,860.70	2.99	1.49	0.15	0.47
Tcr	4,196,030.14	1340.97	65,318.25	5.56	2.67	0.39	0.59
Te	2,734,825.43	851.05	62,020.04	8.26	1.54	0.39	0.56
Tr	683,306.65	192.49	28,093.23	4.48	1.21	0.22	0.26
LUP variant	38,611,870.42	11,207.22	143,006.93	14.61	2.32	0.29	0.38

To clarify results, we compared the average Power ($\overline{P}$) and Energy ($\overline{E}$) production looking at how the minimum solar power required by law for each building differs from the maximum producible energy by each building according to the effective solar radiation. Since the indicators for performing the comparison are not unique, one of the two indicators must be converted to the other. Clearly, a time coefficient can be multiplied by the average power value in order to convert power to energy. Since the unit of measure for the energy indicator is kWh/year, the time coefficient is the number of hours when the solar panels have access to solar irradiation. To do so, we transformed the installable peak power into yearly producible energy multiplying it by 1200 annual utilization hours (solar hours per year). Since sunshine duration varies according to the location on Earth, in our case this indicator is extracted from the solar portal of the Metropolitan area of Turin for the city of Moncalieri [48]. Results are presented in Table 4, which represent the amount of average energy producible (E producible) for each building according to the real solar irradiation and the ones that should be minimally produced by each building every year (E minimal).

Table 4. Energy producible vs. energy required.

Normative Area	$\bar{E}$ producible (kWh/Year)	$\bar{E}$ Minimum (kWh/Year)	Difference (kWh/Year)
Ar1	10,664.48	1848	8816.48
Ar2	8656.84	1824	6832.84
Cemetery area	9803.27	756	9047.27
Environmental Protection Area	28,990.00	4212	24,778.00
Street furniture	12,547.00	1524	11,023.00
Av	12,722.00	2664	10,058.00
Bp	75,779.00	7368	68,411.00
Bpr1	84,064.00	6060	78,004.00
Bpr2	25,104.00	3624	21,480.00
Br	15,363.00	2544	12,819.00
Cp	105,097.00	14,172	90,925.00
Cr	12,329.00	2436	9893.00
Crc	81,290.00	9384	71,906.00
Crs	13,017.00	2268	10,749.00
D	54,985.00	25,956	29,029.00
Ee	15,546.00	2388	13,158.00
Ep	30,498.00	4332	26,166.00
Es	90,699.00	7956	82,743.00
Es1	35,433.00	5796	29,637.00
Fe	40,800.00	4056	36,744.00
Fg	29,566.00	5892	23,674.00
Fh	41,035.00	1824	39,211.00
Fhp	64,626.00	1200	63,426.00
Fi	51,822.00	6648	45,174.00
Fip	15,906.00	2604	13,302.00
Fr	34,850.00	3840	31,010.00
Frp	10,554.00	3420	7134.00
Ft	25,857.00	2892	22,965.00

The field “difference” represents all those LUZ where the installation of solar panel in new buildings according to the minimum requirement by law is inefficient, since the producible energy can be increased, reaching the maximum producible energy by effective solar radiation.

Comparative Analysis of the Energy Indicators

As mentioned earlier, the first indicator represents the total solar energy production potential of the zone, while the second one refers to the regulatory minimum for renewable energy production in the whole zone. Figures 3 and 4 represent the distribution of the total values of these two indicators in the LUZs. In addition, as it can also be noted in Table 2, E and P values differ greatly, with highest values always displayed in E indicators. The evidence from the two maps shows the wide gap between the distribution of renewable energy production in the land use zones and the real solar energy production of the land use zones of Moncalieri. This difference is mainly related to the capacity of the total solar energy production potential (*E*) indicator to get the best of the solar irradiation impacting a specific site. While E producible indicator tends to maximize the solar production setting its parameters to a real assessment of the orographic and morphological conditions of the city of Moncalieri (thus, acknowledging how the solar radiation is distributed and influenced by shaded and lighted areas and can realistically be used to produce energy), the E minimum indicator is just the empirical measurement of a sample-normative minimum requirement which does not account for the specific conditions through which each urban municipality expresses its specific character and production potential. Different from the minimum energy-thresholds required by law—the E producible measure aims to make the best of the solar irradiation according to the morphological features of each site. Additionally, it should be considered that the E minimum values consider only a portion of the rooftop to be destinated at solar energy production while it is considered that another part should be destinated to solar thermal panels while satisfying the thermic consumption and not the energetic one.

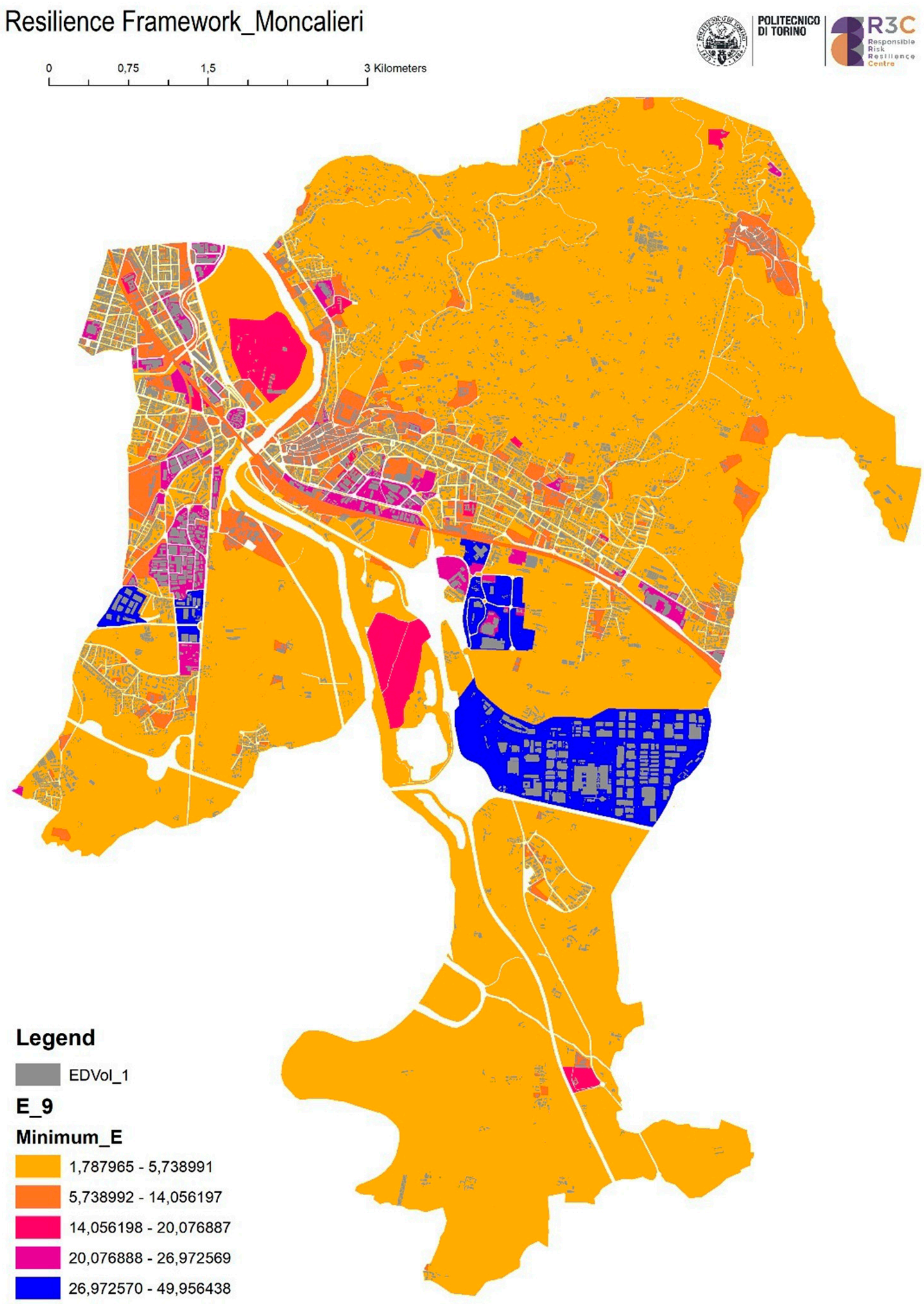


Figure 3. Graphical representation of the regulatory minimum for renewable energy production in the land use zones (P).

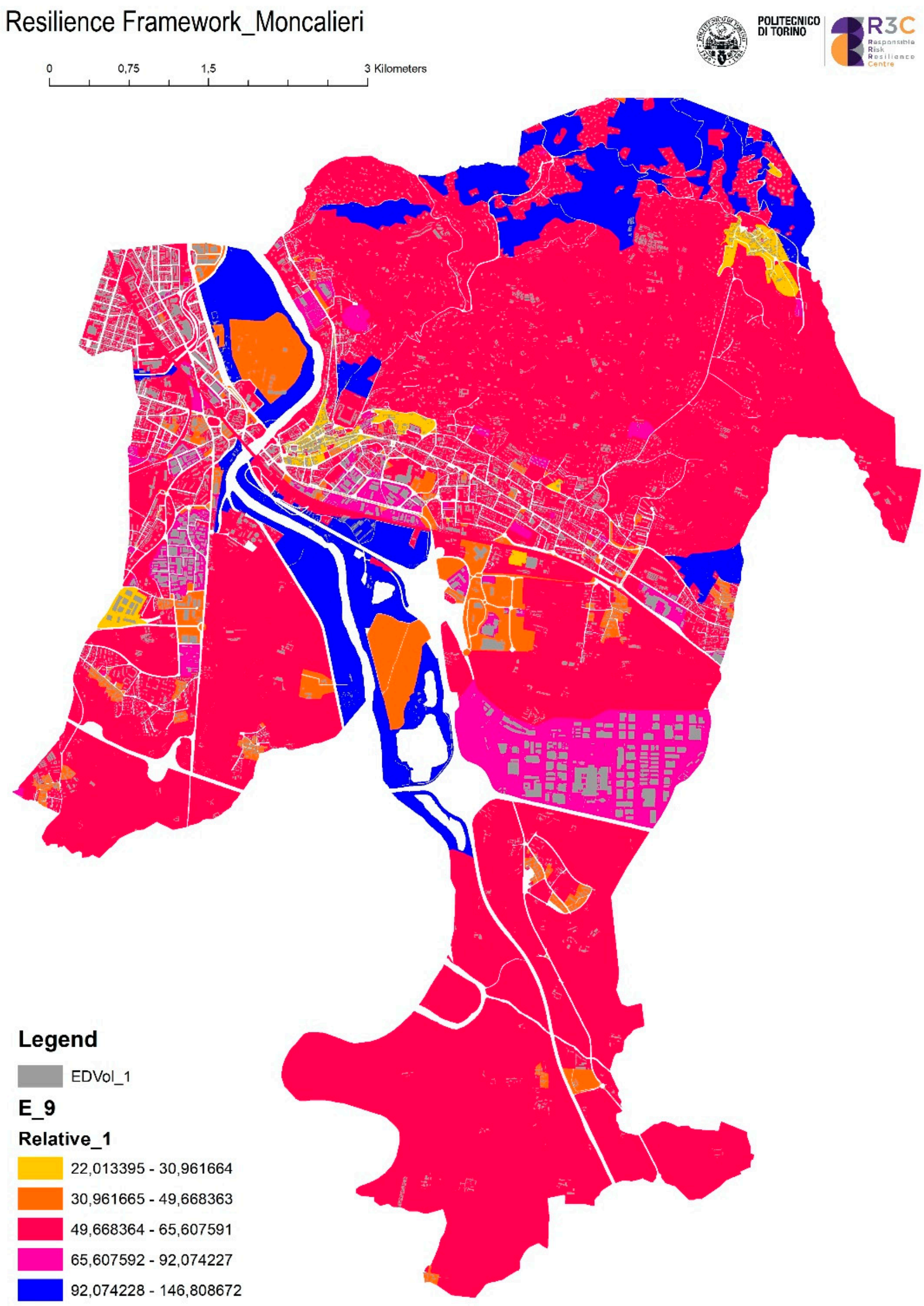


Figure 4. Graphical representation of the total solar energy production potential of the land use zones (E).

As is evident from Figure 5, a regression analysis is performed for estimating the relationship between the two indicators. The results demonstrate a great positive correlation between the two indicators in each normative zone, with an R^2 value equal to 0.98. This is due to the fact that both indicators are proportional to the roof area, but it also verifies that the zones with more solar energy production potential are also asked to produce more renewable energy according to the regulatory measures. In the urban planning field, this positive relationship can become a starting point to introduce more effective and site-specific indications of solar energy production in precise normative zones.

The next figure represents the regression analysis between the average values of E and P. A positive relationship has been verified between the average values of P and E as well. However, the significant difference between the R^2 values of the previous analysis with the latter illustrates that, although the regulatory amount of power has a positive relationship with the energy production potential, when it comes to the smaller scales (such as building scale) the relationship becomes less reliable. The R^2 value for the prior analysis equals 0.98, which means that the obtained equation is reliable for 98% of the indicators, while in the second analysis this value reduces to 0.44 which indicates that the obtained equation is valid for 44% of the indicators. Where this difference comes from, and how it can be interpreted, will be explained in the discussion section of the paper. It is also worth mentioning that, the outlier of Figure 6 refers to Zone D (industrial areas) which positions low-rise widespread buildings where huge roof-surfaces are responsible for the extremely high value of the regulatory minimum of the solar power. If this zone is eliminated from the calculations, the R^2 value increases to 0.73%, which is still significantly lower than this value for the previous regression analysis.

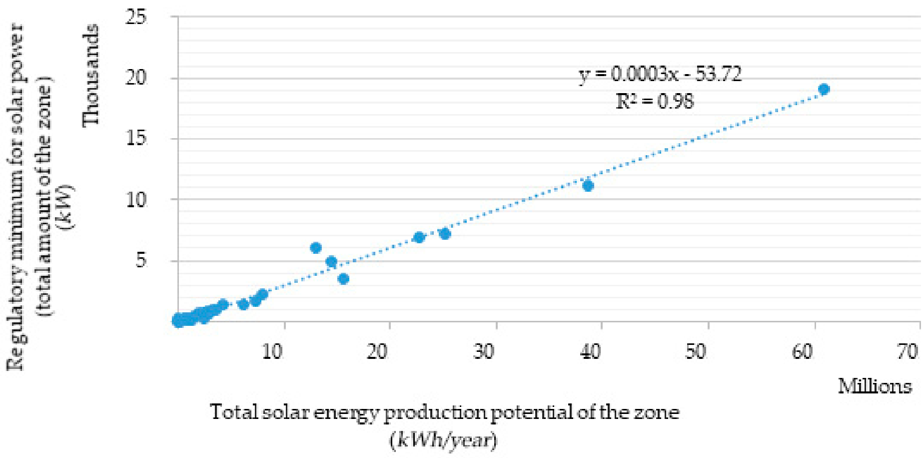


Figure 5. Regression analysis between the total solar energy production potential of the zone (E) in kWh/year, and the regulatory minimum for renewable energy production in the whole zone (P) in *kW*.

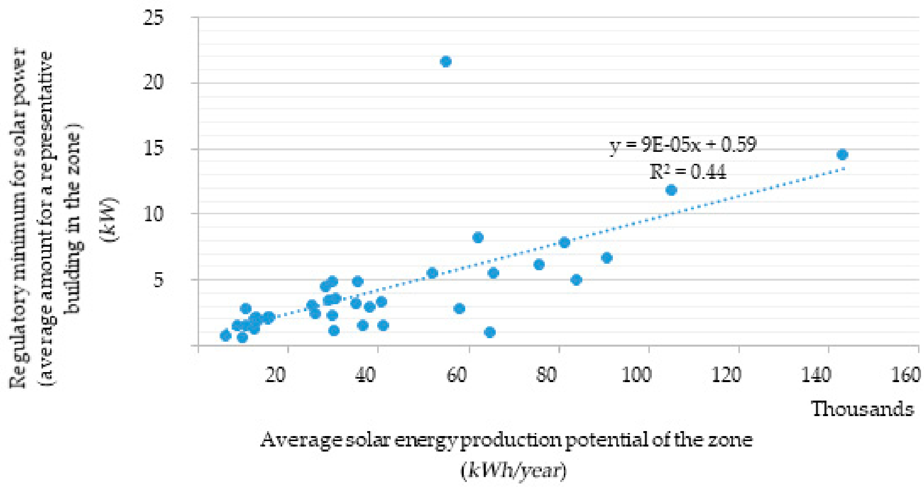


Figure 6. Regression analysis between the average values of solar energy production potential of the zone ($\overline{E}$) in kWh/year, and the regulatory minimum for renewable energy production ($\overline{P}$) in kW.

In the final part of the analysis, the correlations between the indicators of compactness and the indicators of energy were examined through regression analysis. Therefore, the following three figures (a, b, c) present the regression analysis between absolute compactness, site coverage and plot ratio on the one hand, and the solar energy production potential for the unit of roof area, on the other. As it was mentioned earlier in the methodological section, the values of all indicators analyzed in this part are normalized into percentages (values between 0 and 100). The ulterior nine radar charts (d, e, f, g, h, i, l, m, n) and Table 5 summarize the results coming from the comparative analysis of these normalized indicators in the nine zones (the value for each zone is the average value of the corresponding subzones). The reason for selecting the zones instead of subzones in this section is to make the analysis more readable and coherent. The indicators utilized for the radar charts include the percentage of absolute compactness (n.Ac), percentage of site coverage (n.Sc), percentage of plot ratio (n.Pl), percentage of the regulatory minimum amount of energy to be produced in each zone (n.$\overline{P}$) and finally, the percentage of solar energy production potential in each zone (n.$\overline{E}$).

Table 5. Obtained measures for the energetic and morphological indicators in the nine macro-zones of Moncalieri. (all measures are percentages of the total amount).

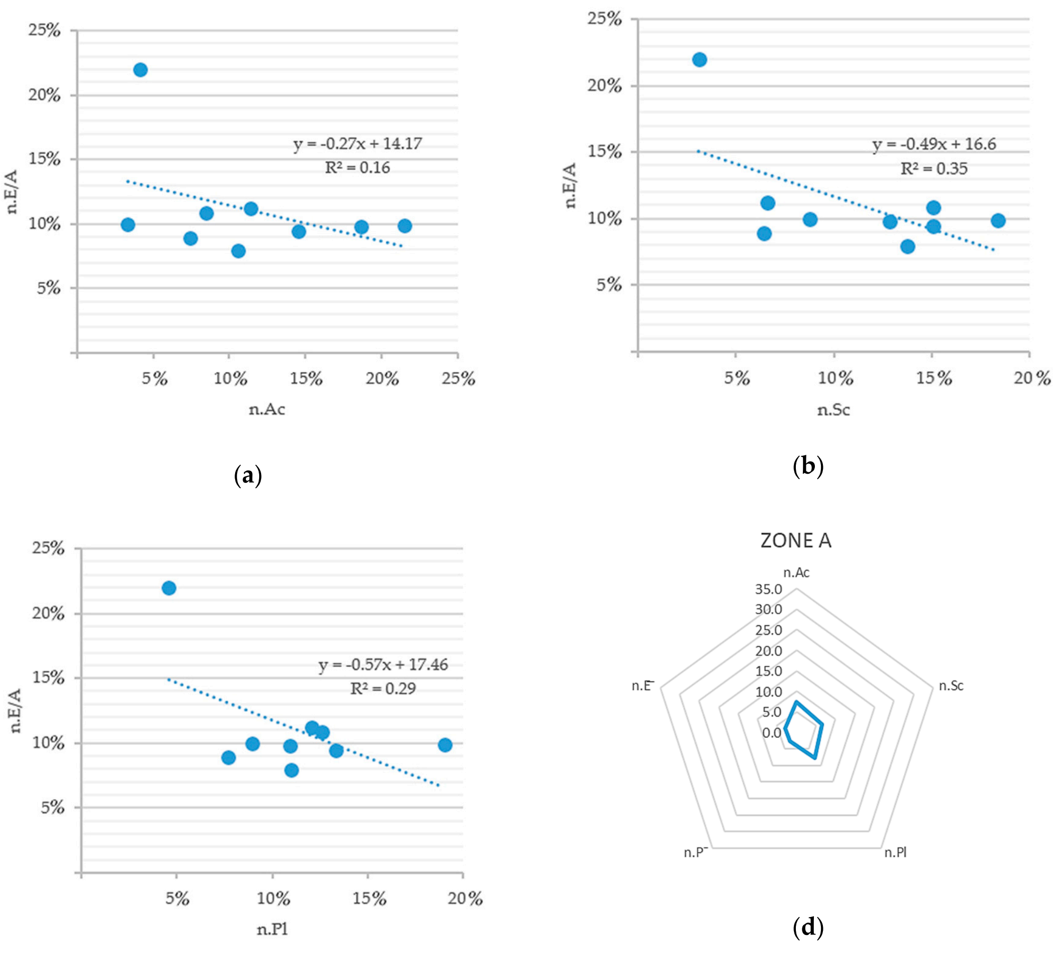
Zone	n.Ac	n.Sc	n.Pl	n.$\overline{P}$	n.$\overline{E}$
A	7.4	6.4	7.7	2.8	2.9
B	21.5	18.4	19.0	6.5	10.5
C	3.3	8.8	8.9	9.3	11.1
D	10.6	13.8	11.0	34.2	11.5
E	8.4	15.1	12.6	6.7	9.0
F	11.4	6.6	12.0	4.5	7.4
S	4.1	3.1	4.6	3.1	6.8
T	14.5	15.0	13.3	9.7	10.9
V	18.7	12.9	10.9	23.1	30.0

It is apparent from the first three figures (a, b, c) that a negative linear correlation exists between each of the compactness indicators and the energy indicator. However, this correlation is not a strong one, since the coefficient of determination (R^2), is relatively low for all three regression results and varies from 0.16 (absolute compactness) to 0.36 (site coverage). Thus, only 16–36% of the variation in the solar energy production of each normative zone of Moncalieri can be related to the variation of these compactness indicators. In general, land use zones with low compactness values produce small values of solar energy, since compactness is an indicator related to the amount of the built-up volume. As a consequence, this value can point out those urban areas where more renewable energy can be produced through the extensive installation of solar panels on roofs. If we now turn to the nine radar charts presented above, it is revealed that the changes in three compactness indicators follow the same trend for different LUZs. The energy indicators though do not follow the same trend in each LUZ. For instance, a remarkable outcome is found in the last zone (the so-called "Other Zones" in the LUP) where the value of both energy indicators is significantly higher than the other zones. Interestingly, the other indicators show that the compactness of the zone is significantly low. Although this result is meaningful for this zone, it does not lead us to conclude that any change in the compactness leads to a change in the energy indicator. This condition is highly influenced by the morphological profile of Moncalieri municipality that, being historical over the layered city, does not present high levels of compactness and density, neither heterogeneous building-height distribution.

4. Discussion

The first significant result coming from our analysis revealed that, in the urban scale, the regulatory minimums for producing renewable energy complies with the solar production potential of the buildings in each zone. According to the formula used for calculating each of these two indicators, this convergence is due to the building footprint (S), which plays the key role for both indicators. However, the second regression analysis reports that this convergence becomes less reliable when the scale of analysis alters. Since the second pair of energy indicators are the representatives of the average values (a sample building in each zone), the significant decrease in the R^2 value demonstrates that the relationship between the production potential and regulatory minimum weakens at building scale. This implies that lots of buildings with the same value of the regulatory minimum amount of renewable energy production, in reality, have different amounts of production potential. This unanticipated finding can be explained by taking a deeper look at both indicators. The key variable in making this divergence corresponds with the accumulated annual solar irradiation in the normative zone or Hs (kWh/m^2/a). Undoubtedly, the more solar irradiation on a rooftop is accumulated, the more solar energy can be produced for the building. However, this variable is not considered in the calculation of the regulatory minimum for renewable energy production.

Additionally, as can be seen in Table 4, in all zones, the value of regulatory minimum for renewable energy production is considerably less than the real renewable energy production potential. The results obtained from the difference between these two values (the last column) shows an average 86.02% of the inefficiency ratio. This means that, on average, any zone is requested to produce only 13.98% of its real potential. Such observations may support the hypothesis that it is necessary to redefine the energy-related regulations and calculations in a way that the accumulated annual solar irradiation Hs (kWh/m^2/a) takes an active part in the formula of mandatory minimum for renewable energy production. Such integration between site-specific solar radiation models with the local regulations by LUZ is necessary to meet the real possibility of reconverting in an effective (achievable) and efficient way the transition to a more resilient energy proof city. It is displayed by Figure 7 that morphological conditions are quite heterogeneous in the city and that such heterogeneity poses a significant effect on the achievable quantity of energy produced by solar radiation.



(a) (b) (c) (d)

Figure 7. *Cont.*

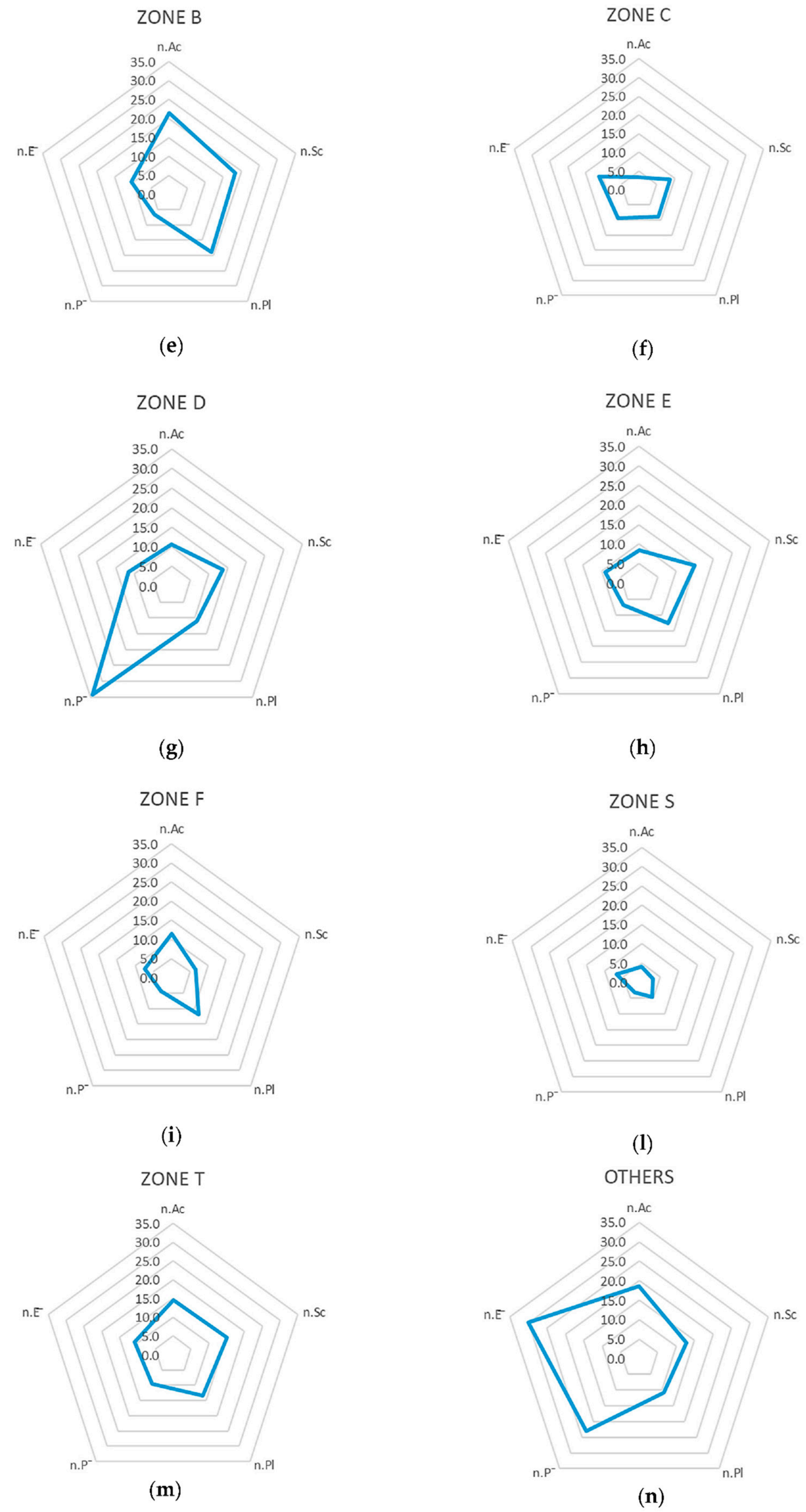


Figure 7. (**a**) regression analysis between n.E/A and n.Ac; (**b**) regression analysis between n.E/A and n.Sc; (**c**) regression analysis between n.E/A and n.Pl; (**d**–**n**) Radar chart of the comparative analysis between compactness indicators and the energy indicator in different normative zones; n.Ac is the normalized

absolute compactness, n.Sc is the normalized site coverage, n.Pl is the normalized plot ration, n.P⁻ is the normalized regulatory minimum for renewable energy production, and n.E/A is the normalized solar energy production potential for the unit of building roof area in each zone. (All values are percentages).

If the target is to produce regulatory acts that promote the transition toward a more efficient energy system, the knowledge of the "real" orographic and morphologic conditions of the urban LUZ plays a vital role in defining the reliable target, especially when the regulation concerns the minimum urban units—the buildings. Therefore, further studies to introduce the correlation between morphology and irradiation are strongly suggested, especially in those countries where solar energy is already a great and abundant source. In this way, it will be possible to realize that urban morphology represents an efficient voice to develop and transform also an old and over-layered city into an example of energy-sustainability [1]. There are several issues regarding the selection of new criteria in energy-related regulations, mainly referred to data availability to conduct calculations. Solar data access may be a relevant challenge for many local governments [7] in many countries, because they may lack adequate technical, economic and human resources to collect them.

However, the methodological implementation here mentioned is worthy of attention in the international debate, as it not only makes the required amount reasonable for the areas that cannot meet the minimum, but also can lead to an increase of the minimum required values for the zones which are more capable of producing solar energy according to their local and morphological characteristics. To be more specific, the results suggest that there is a considerable number of zones in which the minimum required amount of renewable energy production can be increased significantly. This way of realizing that the urban morphology has a strong connection with the solar potential may significantly contribute to evaluating the large-scale solar potential for roofs in existing urban areas, although it has been assessed so far for only a few countries [44]. New solar technologies may then improve the roof potential and make it evident for both public and private actors. Additionally, even if longer time is needed, the cumulative amount of solar energy produced through inclusion, modification and development of proper urban form can have relevant impacts on the energy budget at urban scale [49]. Furthermore, achieving progressive solar installation will encourage a significant amount of economic activities related to solar industries. Basically, the main economic impacts can be grouped in: "Gross impacts", which account for the activities related to the solar system construction, installation, maintenance and research spending; and "net impacts" that correspond with the difference between the solar-scenario and the current-one [50]. Within this overall background, local investments in new solar technologies may lead to specific economic impacts as: The "output", such as the value of sales considering both reductions or increases in business stocks; the "personal income", referred to the total payment to workers and business owners; the "job" impact with both full- and part- time employment; and the "tax expenses" for different national and local jurisdictions. Some benefits are also evident, as the advantages compared to an energy system without renewables, the benefits of reduced energy losses and the advantages of reduced negative environmental externalities [51]. In addition, thanks to technological improvements and cost reductions of last decades, solar panels systems are increasingly cost-competitive, affordable, and rapidly expanding [52]. The progressive understating of solar energy potentials in cities will consent to plan a priority order about the more effective interventions and economic investments [27]. It is a scientific responsibility to communicate these potentials to local authorities, professionals and citizens and to prove to them how investments today could save public and private resources in the future [7]. GIS-based assessments at a territorial scale can support this process and sensitize behaviors of both individual citizens and economic operators [27]. Urban governance needs to deal with the issues of higher initial investment costs of resilient energy technologies to reduce energy consumption and encourage local technology development [8].

Furthermore, there is a close relationship between energy production potential and urban features, such as morphological and topographical alterations. The results reveal that even in the city of

Moncalieri—Which is not an extremely high compacted city—the compactness of the zones has a negative correlation with the solar energy production potential in the zones. Although this correlation was not a strong one, it underlines the importance to rethink more, in general, the role of spatial-urban planning as a strategic tool, capable of influencing land use, property rights, mobility, urban design and renewable energy production in the building sector. This new approach highlights that to understand and assess the solar energy potential in urban areas, morphology-related variables should be included in the early stages of the design and planning process [28]. For instance, this passage may highlight those LUZ where it is more convenient to install new solar panels because of the available roof-surfaces, or may introduce in the land use planning practice some "urban compactness-thresholds", "alignment of rooftops", "distance between solar-radiated surfaces" or "height of new solar energy-producing buildings". Hence, this model has the potential to slightly transform the existent city, introducing new energetic thresholds on the real/effective production capacity while maximizing the solar radiation effect. In this sense, it will become increasingly important to understand and possibly simplify the typical requirements faced by technicians, designers and planners [53]. In fact, when dealing with new design or re-design of urban areas, operators usually have to do with regulations, requirements and restrictions related to building characteristics, morphological targets, economic availabilities, etc. The integration of solar energy potential can make this process even more complicated, but the effort for a better balance is needed. To simplify the procedure, the use of some morphological features over others should be developed, according to studies that show the impact of each variable on the overall solar energy production of a LUZ or of its buildings.

Finally, our analysis is restricted to the calculation of the solar energy production from the rooftops, and this is a limit according to the most advanced solar production techniques for vertical structures (e.g., building walls, facades, and windows). Furthermore, while the area of the whole roofs is usually very high, only a fraction of it has the potential to produce an acceptable amount of energy. However, there are three main reasons that make this limitation negligible. First, the present regulations of the city and the conditions of many buildings make it almost impossible to use the facades as a potential energy source for the existing buildings. Second, usually, the amount of solar energy that can be collected on roofs is much higher than that on facades. Additionally, regardless of the roof type or slope, considering the available technologies in the region, and taking advantage of design solutions, we believe that it is possible to install solar panels on almost every roof [53]. Third, even if the calculation is restricted to the rooftops, the existence, absence, weakness, or significance of the correlation between the energy production and the real conditions of each case of study should be assessed, analyzed, demonstrated by in-depth solar radiation assessment as a minimum requirement to re-design local regulations and normative solutions at the city-level by the LUP. Finally, despite the utility of specific data on the current-percentage of buildings with roof-panels, we do not know exactly this quantity as data are not available. However, thanks to the information collected from Portale Altasole (http://atlasole.gse.it/atlasole/), we found out that in 2010 only 274 solar panel plants where installed in the city on a total of 6.200 buildings, with a total power of 6.313 kW (corresponding to 612 MWh) [54]. This information, regardless of the fact that some buildings may not be suitable for solar plants, highlights the room for a local long-term transition towards solar energy production.

In future steps of this research, we may investigate how to be more effective in such analytical results, selecting certain sample areas and providing a direct link between assessment and policy making with practical and normative implications.

5. Conclusions

Since the city is a highly-populated place with the most concentrated human activity, there is an increasing need to move towards a more sustainable development—where urban land use patterns are coherent with the morphological profile and energy producibility through solar source [27]. The growing general interest for including energy topics (in the land use planning process and in the search for sustainable urban forms) is also reinforced by the need to address future changes with more energy-efficient cities [55]. Mainstreaming energetic resilience by morphological study and assessment in ordinary municipal land use planning can become an important step for developing tools and data to drive urban energy resilience. Indicators are also useful to inform decision making by local authorities, and their outcomes can improve urban energy system's preparation, absorption and adaptation abilities [7]. In this study, we highlight the need to simplify, integrate and track solar energy issues at the local scale, in order to favor the route to resilience and to more sustainable models of urban planning. To achieve the overmentioned sustainable principles of "availability", "accessibility", "affordability" and "acceptability", any urban systems should be able to "prepare and plan for, absorb, recover from, and then successfully adapt to" any risks or disturbs over time [8]. In this sense, the proposed GIS model could become a support-tool for interactive decisions, based on the real characteristics of the municipal building stock. Moreover, looking to the model contents, we understand the need to use building regulations not only to strengthen and implement the law (specifically here, the Legislative Decree 28/2011), but also to introduce practices for "building better" than the regulatory requirements. The benefits of this approach might lead for instance to voluntary actions in favor of sustainable energy that can be recognized by the municipal land use planning with economic incentives and financial mechanisms, such as discounts on construction costs, volumetric bonus or tax benefits (for example). To reach this point, however, municipal land use regulations need to integrate progressively models like the one elaborated in this work, in order to realistically evaluate where it is convenient to adopt these actions at the local scale. Furthermore, these new elements have to be supplemented by the efforts of the local level in favor of bottom-up activities and engagement [56], in order to promote the use of good practices also at smaller scales.

One of the most evident and replicable findings of this study is that urban design has a high impact on solar energy production, through the design of buildings, forming urban geometry, determining land uses, etc. Nevertheless, the difficulty in understanding urban complexity creates limitations for intertwining theory and practice, especially in the case of the urban planning field. However, when dealing with sustainable energy issues at the local level, these aspects and results may become permanent support in the decision-making process, as well as a relevant requirement for achieving energetic resilience. For the specific case-study of this research, the Energy Attachment should not be seen as a separate and exhaustive document of the municipality, but rather part of the "corporate culture" of municipal planning in the "Era of energy transition" [1]. The energy attachment should be integrated into the municipal plan, and its technical contents should affect the localization of zones, their dimensions, their functionalities and morphologies also in the light of the urban energy strategy.

More broadly, evidence shows that the conscious installation of photovoltaic systems in large urban contests can offer a sustainable contribution to energy needs and savings, but in parallel has to be supported by proper GIS or grid models to guide the city energy balance since the early planning process [49]. Urban planners can play a central role in making these models more comprehensible, identifying the status-quo, patterns, potential threats and emergencies [8]. They should then become more and more aware of the advantages to include energy resilience among their objectives and to update development policies with renewable energy implications. Furthermore, planners should also coordinate policy makers, stakeholders and private actors in a collective strategy of sustainable and smart energy systems at territorial level.

For all these reasons, instead of focusing on short-time results, the municipal approach should also consider the morphological features (since the physical structure of cities is also relatively permanent), in order to clearly recognize the most productive areas from those more compromised, shady and geometrically inconvenient for energy purposes in the long-run. The use of realistic data may guide the exploration of future scenarios of land use and urban expansion, further integrating the solar energy potential in urban planning [57]. Finally, yet importantly, the traditional preference to keep dated policies and add plans within an already overabundant planning system hinders the reform of the way of intervening and makes it too fragmented. In relation to that, we highlight that this planning methodology risks too much of a singular focus on a single action or project, leaving the whole city “unchanged” and “unaffected” from a concrete energy-shift. On the contrary, developing the capacity to simulate the urban energy profile, starting from the morphological properties, may lead to an efficient, energetic condition capable of responding to future energy requirements, as well as to local long-term perspectives on all levels.

Author Contributions: Conceptualization, G.B., S.S.; methodology, G.B., G.M. and S.S.; empirical analysis, D.M.D., A.B. and S.S.; writing and editing, D.M.D., A.B., S.S. and G.M.; supervision, G.B. and G.M.; project administration, G.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This manuscript is a product of the project “Resilient Transition and Sustainable Energy” of the Responsible Risk Resilience Centre (R3C) of Politecnico di Torino (see http://www.r3c.polito.it/).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. De Pascali, P.; Bagaini, A. Energy transition and urban planning for local development. A critical review of the evolution of integrated spatial and energy planning. *Energies* **2019**, *12*, 35. [CrossRef]
2. Jacobs, P. Energy and form, an ecological approach to urban growth. *Urban Ecol.* **1976**, *2*, 192–193. [CrossRef]
3. Olgyay, V. *Design with Climate*; Princeton University Press: Princeton, NJ, USA, 2015.
4. Clark, W.A.V.; Martin, L.; March, L. *Urban Space and Structures*; University Press Cambridge: Cambridge, UK, 1975; Volume 65.
5. Liddell, H.L. *Design With Nature*; American Museum of Natural History New York: New York, NY, USA, 1976.
6. Owens, S. *Energy, Planning and Urban Form*; Pion Ltd.: London, UK, 1986.
7. Mutani, G.; Todeschi, V. An urban energy atlas and engineering model for resilient cities. *Int. J. Heat Technol.* **2019**, *37*, 936–947. [CrossRef]
8. Sharifi, A.; Yamagata, Y. Principles and criteria for assessing urban energy resilience: A literature review. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1654–1677. [CrossRef]
9. Brunetta, G.; Ceravolo, R.; Barbieri, C.A.; Borghini, A.; de Carlo, F.; Mela, A.; Beltramo, S.; Longhi, A.; De Lucia, G.; Ferraris, S.; et al. Territorial resilience: Toward a proactive meaning for spatial planning. *Sustainability* **2019**, *11*, 2286. [CrossRef]
10. Gibson, R.B. Sustainability assessment: Basic components of a practical approach. *Impact Assess. Proj. Apprais.* **2006**, *24*, 170–182. [CrossRef]
11. Sharifi, A.; Yamagata, Y. A Conceptual Framework for Assessment of Urban Energy Resilience. *Energy Procedia* **2015**, *75*, 2904–2909. [CrossRef]
12. Brunetta, G.; Salata, S. Mapping urban resilience for spatial planning-A first attempt to measure the vulnerability of the system. *Sustainability* **2019**, *11*, 2331. [CrossRef]
13. Meerow, S.; Newell, J.P.; Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* **2016**, *147*, 38–49. [CrossRef]
14. Brunetta, G.; Caldarice, O. Spatial Resilience in Planning: Meanings, Challenges, and Perspectives for Urban Transition. In *Sustainable Cities and Communities*; Leal Filho, W., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T., Eds.; Springer International Publishing: Cham, Switzerlan, 2019; pp. 1–14. ISBN 978-3-319-71061-7.
15. Meerow, S.; Newell, J.P. Urban resilience for whom, what, when, where, and why? *Urban Geogr.* **2019**, *40*, 309–329. [CrossRef]
16. Meerow, S.; Newell, J.P. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landsc. Urban Plan.* **2017**, *159*, 62–75. [CrossRef]
17. Grilo, F.; Pinho, P.; Aleixo, C.; Catita, C.; Silva, P.; Lopes, N.; Freitas, C.; Santos-Reis, M.; McPhearson, T.; Branquinho, C. Using green to cool the grey: Modelling the cooling effect of green spaces with a high spatial resolution. *Sci. Total Environ.* **2020**, 138–182. [CrossRef] [PubMed]
18. Parliament, E. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. *Off. J. Eur. Union* **2010**, 13–35.
19. Parliament, E. Directive 2012/27/EU of the European Parliament and of the council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. *Off. J. Eur. Union* **2012**, *L315/1*, 1–56.

20. European Union. European Parliament Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. *Off. J. Eur. Union* **2009**, *140*, 16–62.
21. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market. In *Compendium of Sustainable Energy Laws*; European Commission: Brussels, Belgium, 2010; pp. 394–401.
22. Carrillo-Hermosilla, J.; Del Río, P.; Könnölä, T. Diversity of eco-innovations: Reflections from selected case studies. *J. Clean. Prod.* **2010**, *18*, 1073–1083. [CrossRef]
23. European Union. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. *Off. J. Eur. Union* **2018**, *5*, 82–209.
24. *Ministry of Economic Development Piano Nazionale Integrato per l'Energia e il Clima*; Ministero dello Sviluppo Economico: Rome, Italy, 2019.
25. Della Repubblica, P. *Attuazione Della Direttiva 2009/28/CE Sulla Promozione Dell' Uso Dell' Energia da Fonti Rinnovabili, Recante Modifica e Successiva Abrogazione Delle Direttive TITOLO I FINALITA' E OBIETTIVI*; Gazzetta Ufficiale della Repubblica Italiana: Rome, Italy, 2011.
26. *Decreto 26 giugno 2015. Adeguamento del Decreto del Ministro dello Sviluppo Economico, 26 Giugno 2009-Linee Guida Nazionali per la Certificazione Energetica Degli Edifici. (15A05200) (GU Serie Generale n.162 del 15-07-2015-Suppl. Ordinario n. 39)*; Gazzetta Ufficiale: Rome, Italy, 2015.
27. Mutani, G.; Casalengo, M.; Ramassotto, M.A. The effect of roof-integrated solar technologies on the energy performance of public buildings: The case study of the City of Turin (IT). In *Proceedings of the INTELEC, International Telecommunications Energy Conference (Proceedings)*; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2019; Volume 2018-Octob.
28. Gancheva, M.; O'Brien, S.; Crook, N. *Models of Local Energy Ownership and the Role of Local Energy Communities in Energy Transition in Europe*; European Committee of the Regions: Brussels, Belgium, 2018; ISBN 9789289509893.
29. Council of the European Union Proposal for A Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources (Recast). Available online: http://www.consilium.europa.eu/en/press/press-releases/2018/06/27/renewable-energy-council-confirms-deal-reached-with-the-european-parliament/ (accessed on 17 April 2020).
30. International Energy Agency How Solar Energy Could Be the Largest Source of Electricity by Mid-Century. Available online: Http://Www.Iea.Org/Newsroomandevents/Pressreleases/2014/September/How-Solar-Energy-Could-Be-the-Largest-Source-of-Electricity-By-Mid-Century.Html (accessed on 19 April 2020).
31. Legge del 30 Marzo 1976, n. 373. Norme per il Contenimento del Consumo Energetico per Usi Termici Negli Edifici. (GU Serie Generale n.148 del 07-06-1976). Available online: https://www.gazzettaufficiale.it/eli/id/1976/06/07/076U0373/sg (accessed on 27 May 2020).
32. L. 9 Gennaio 1991, n. 10-Norme per L'attuazione del Piano Energetico Nazionale in Materia di Uso Razionale Dell'energia, di Risparmio Energetico e di Sviluppo Delle Fonti Rinnovabili di Energia (G.U. 16 Gennaio 1991, n. 13, S.O.)|Ministero Dell'ambien. Available online: http://www.minambiente.it/normative/l-9-gennaio-1991-n-10-norme-lattuazione-del-piano-energetico-nazionale-materia-di-uso (accessed on 17 April 2020).
33. Legge Regionale-LR 24/03/2000, n.31; Disposizioni per la Prevenzione e Lotta All'inquinamento Luminoso e per il Corretto Impiego Delle Risorse Energetiche. (B.U. 29 Marzo 2000, 2° suppl. al n. 13). Available online: http://arianna.consiglioregionale.piemonte.it/base/leggi/l2000031.html (accessed on 27 May 2020).
34. Decreto Legislativo-D.Lgs 3/04/2006, n.152; Norme in Materia Ambientale (G.U. n. 88 del 14 Aprile 2006). Available online: https://www.bosettiegatti.eu/info/norme/statali/2006_0152.htm (accessed on 27 May 2020).
35. Legge Regionale 28 Maggio 2007, n. 13. Disposizioni in Materia di Rendimento Energetico Nell'edilizia. (B.U. 31 Maggio 2007, n. 22). Modificata da l.r. 03/2009, l.r. 20/2009, l.r. 22/2009, l.r. 30/2009, l.r. 05/2012. Available online: http://arianna.consiglioregionale.piemonte.it/base/coord/c2007013.html (accessed on 27 May 2020).
36. Decreto del Presidente della Repubblica 2 Aprile 2009, n. 59 Regolamento di Attuazione Dell'articolo 4, Comma 1, Lettere a) e b), del Decreto Legislativo 19agosto 2005, n. 192, Concernente Attuazione della Direttiva 2002/91/CE sul Rendimento Energetico in. Available online: http://www.energia.provincia.tn.it/binary/pat_agenzia_energia/normativa/DPR_59_2009.1248339845.pdf (accessed on 27 May 2020).
37. Decreto Legislativo-D.lgs 3/03/2011, n. 28. Attuazione Della Direttiva 2009/28/CE Sulla Promozione Dell'uso Dell'energia da Fonti Rinnovabili, Recante Modifica e Successiva Abrogazione Delle Direttive 2001/77/CE e 2003/30/CE (G.U. n. 71 del 28 Marzo 201. 2011. Available online: https://www.minambiente.it/sites/default/files/dlgs_03_03_2011_28.pdf (accessed on 27 May 2020).

38. Repubblica Italiana. Legge 3 Agosto 2013, n.90-Conversione, con Modificazioni, del Decreto-Legge 4 Giugno 2013, n.63 Disposizioni Urgenti per il Recepimento della Direttiva 2010/31/UE del Parlamento Europeo e del Consiglio del 19 Maggio 2010, Sulla Prestazione Energetica ne. Available online: https://www.gazzettaufficiale.it/eli/id/2013/08/03/13G00133/sg (accessed on 27 May 2020).
39. Legge Regionale 11 Marzo 2015, n.3. Disposizioni Regionali in Materia di Semplificazione. (BU 12 Marzo 2015, n. 2° suppl. al n. 10). Available online: http://arianna.consiglioregionale.piemonte.it/base/coord/c2015003.html (accessed on 17 April 2020).
40. Ministero Dello Sviluppo Economico. *Decreto Interministeriale 26 Giugno 2015-Applicazione Delle Metodologie di Calcolo Delle Prestazioni Energetiche e Definizione Delle Prescrizioni e dei Requisiti Minimi Degli Edifici*; Ministero Dello Sviluppo Economic: Rome, Italy, 2015.
41. Statistiche Istat, Popolazione Residente al 1° Gennaio 2020, Moncalieri. Available online: http://dati.istat.it/ (accessed on 17 April 2020).
42. *BDTre Digital Topographic Database of Piedmont Region*; Regione Piemonte: Turin, Italy, 2017.
43. Istituto Nazionale di Statistica, ISTAT. *Censimento Della Popolazione e delle Abitazioni 2012. GU n.209 del 18/12/2012*; Gazzetta Ufficiale: Rome, Italy, 2012.
44. Mohajeri, N.; Upadhyay, G.; Gudmundsson, A.; Assouline, D.; Kämpf, J.; Scartezzini, J.L. Effects of urban compactness on solar energy potential. *Renew. Energy* **2016**, *93*, 469–482. [CrossRef]
45. Mutani, G.; Vicentini, G. *Evaluating the Potential of Roof-Integrated Photovoltaic Technologies Using An Open Geographic Information System*; ÜBER: Turin, Italy, 2017; ISBN 978-3-9812053-6-7.
46. Mutani, G.; Vodano, A.; International, M.P.I. Photovoltaic solar systems for smart bus shelters in the urban environment of turin (Italy). In Proceedings of the 2017 IEEE International Telecommunications Energy Conference (INTELEC), Broadbeach, Australia, 22–26 October 2017; pp. 20–25.
47. *Piedmont Region Energy Consumptions Database (2010–2017)*; Sustainable Energy Department: Turin, Italy.
48. Il Portale Solare-Città Metropolitana di Torino. Available online: http://www.cittametropolitana.torino.it/cms/ambiente/risorse-energetiche/osservatorio-energia/portale-solare (accessed on 17 April 2020).
49. Marshall, J.D. Energy-efficient urban form. *Environ. Sci. Technol.* **2008**, *42*, 3133–3137. [CrossRef]
50. Grover, S. *Energy, Economic, and Environmental Benefits of the Solar America Initiative*; National Renewable Energy Laboratory: Golden, CO, USA, 2007.
51. IRENA, C. *The Socio-Economic Benefits of Large-Scale Solar and Wind: An econValue Report*; International Renewable Energy Agency (IRENA): Abu Dhabi, UAE, 2014.
52. Fritsche, U.; Berndes, G.; Cowie, A.; Dale, V. Energy and land use. *Work. Pap. Glob. L. Outlook* **2017**, 14–15.
53. Sarralde, J.J.; Quinn, D.J.; Wiesmann, D.; Steemers, K. Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. *Renew. Energy* **2015**, *73*, 10–17. [CrossRef]
54. Portale Atlasole, Gestore dei Servizi Energetici–GSE S.p.A. Available online: http://atlasole.gse.it/atlasole/ (accessed on 22 May 2020).
55. Energy, S.O.-A. *Land-Use Planning for Energy Efficiency*; Elsevier: Berlin/Heidelberg, Germany, 1992.
56. O'Brien, G. Vulnerability and resilience in the European energy system. *Energy Environ.* **2009**, *20*, 399–410. [CrossRef]
57. Amado, M.; Poggi, F. Solar energy integration in urban planning: GUUD model. In *Proceedings of the Energy Procedia*; Elsevier Ltd.: Amsterdam, The Netherlands, 2014; Volume 50, pp. 277–284.